GRASSHOPPER FEEDING BEHAVIOR AND THE DEVELOPMENT OF EDIBLE CARRIERS FOR GRASSHOPPER CONTROL AGENTS (1)

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INTRODUCTION

Our research on the isolation and identification of behavioral components of grasshopper host plant selection has shown the potential for utilizing behavior in applied programs for the evaluation and management of grasshopper populations.

The term "grasshopper" should be interpreted as a few species common to the grasslands of North Dakota. Species are mentioned in the tables.

Grasshoppers are a natural and important constituent of grassland ecosystem. Most species are benficial and management of populations would include positive as well as negative aspects. However, there are times when, coincident with certain weather conditions and land usages, grasshopper populations are of a size and composition that they damage vegetation. There is a need to be able to recognize and evaluate grasshopper populations, weather conditions, and land usage in order to minimize damage to grasslands.

At present, there is neither a real prospect for managing weather or climate nor is it easy to make rapid changes in land use. Within the past 30 years it has been possible to make drastic reductions in grasshopper populations by the application of chemical control agents such as aldrin, dieldrin, or malathion. However, the effect of these compounds on non–target organisms has been of great concern and restrictions have been placed on their use. Still, it does not appear possible to maintain an adequate supply of high quality agricultural products without the use of some control agents.

The ideal of any insect control or pest management program always has been to have the maximum effect on the target organism and the minimum effect on all other organisms.

(1) *Published with the approval of the Director of the North Dakota Agricultural Experiment Station as Journal article Nº 736.*

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One approach to this ideal would be the development and utilization of extremely selective control agents which would affect only a particular species. Because of the high cost of developing and producing chemical control agents the emphasis is more likely to be on the development of chemicals effective against a broad spectrum of pests, rather than selected ones. The development of biological control agents such as those indicated by the outstanding work of Dr. John Henry offers possibilities for this approach, (Henry and Oma, 1974).

Another approach to this ideal would be to selectively direct the application of the control agent so that only the target organisms would be affected, despite employment of a broad spectrum control agent.

The advantages of selective application include:

1. Less control agent is needed since less is lost or misdirected during application.
2. Fewer non–target organisms are affected by the control agent.
3. Selective suppression is possible. One may not desire to eradicate a population but only reduce its impact on a desirable feature. Since grasshoppers are an integral part of the grasslands environment, their sudden and complete disappearance may have adverse side effects.

Obviously, combining the selectivity of the control agent with a selective application would give maximum benefit. Drumond et al (1975) developed a Performance Index based on the inverse relationship of Pest Control Efficiency to Cost of Control.

$$\text{Performance Index (PI)} = \frac{\text{Pest Control Efficiency}}{\text{Cost to Produce Control}}$$

Efficiency was the inverse relationship of Pest Control Efficiency to Amount of Pesticide used.

$$\text{Pest Control Efficiency (PCE)} = \frac{\text{Pest Reduction}}{\text{Amount of Pesticide Used}}$$

Modifying this equation to account for the effects on non–target or non–pest organisms weights it in favor of selective control.

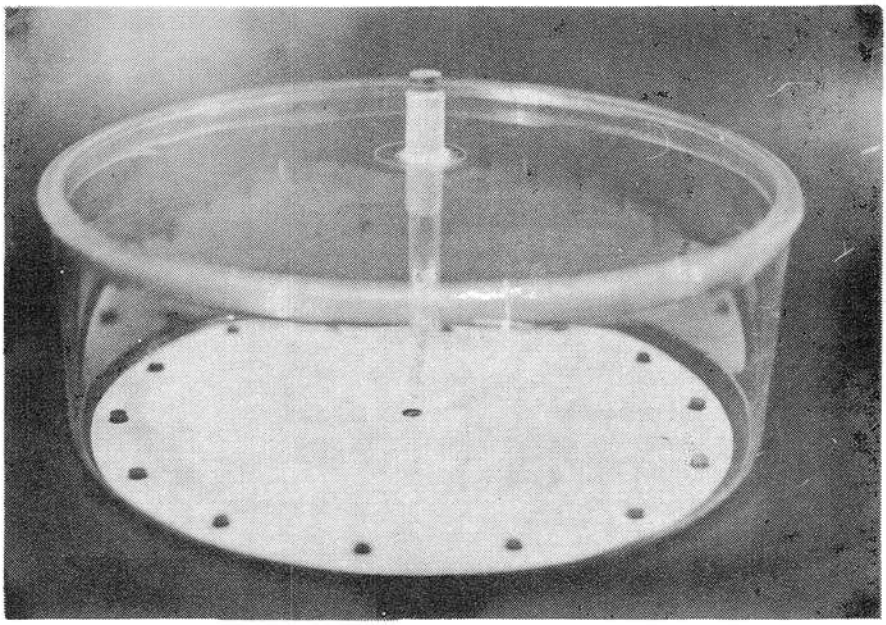
$$\text{PCE} = \frac{\text{Pest Reduction} - \text{Non–Pest Reduction}}{\text{Amount of Pesticide Used}}$$

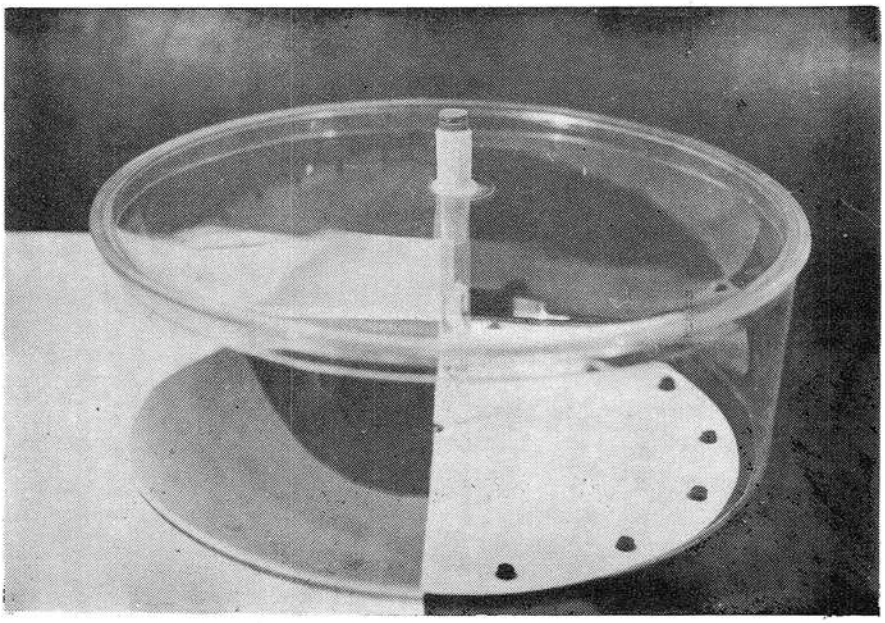
GRASSHOPPER BEHAVIOR

Before considering further the control aspect, we should describe some behavioral responses that were pertinent to the development of a control method. Our approach to this was mainly observational, utilizing intact insects in controlled laboratory and greenhouse conditions and in field situations with little or no attempt to alter existing conditions. Responses to stimuli were determined by direct observations of grasshoppers, often with time-lapse cinematography and indirectly by the ingestion of edible preparations as indications of activity in response to stimuli. ^{32}P was used to label preparations with the detection of radioactivity as an indication of feeding responses.

Grasshoppers are diurnal and more active under illumination than in the dark. They exhibit a positive photo-orthokinesis, and make undirected movements that keep them in illumination and out of darkened areas. They also show positive photoklinokinesis (Mulkern, 1967, 1969).

An experiment related food consumption to illumination in small plastic arenas 21 cm. x 8 cm. high (Figs. 1-3). Fourteen equal food tablets were arrayed around the





Figures 1-2. Plastic arenas with paper discs and outer cover used in feeding behavior experiments.

perimeter of a paper disc inserted on the bottom of the arena. The disc was all white, all black, or 1/2 black and 1/2 white. A black paper cover could be fitted to shield 1/2 of the arena from direct light. Since one effect of shading was to darken the background upon which the food was displayed, having the disc black could mimic this. With an all white or all black disc there was no detectable pattern of selection among the tablets (Fig. 4). With a black and white disc only 1 of 4 replicates had a significant difference in ingestion as determined by a t-test although there was a tendency for greater feeding on tablets in the white portion. Covering 1/2 of the arena which had a white disc resulted in significantly less feeding in the shaded portion. Covering the black 1/2 of a black and white disc also resulted in significantly less feeding in the shaded portion. Covering the white half of the disc resulted in greater ingestion in the black unshaded part, but the difference in mean ingestion was not significant. In part this was because of the large amount of feeding that took place on the tablets on the white 1/2 near the juncture of the 2 halves. Since all of the food tablets were the same, feeding was influenced by the response to illumination.

In arenas with alternate black and white segments there was significantly greater feeding on the tablets displayed on the white segments. Possibly the greater contrast of the dark tablets on the white display than on the dark display was responsible.

Grasshoppers probably feed at night in the field. However, in several years of analyzing the crops contents of grasshopper we have found that the incidence of empty remains high several hours after sunrise until it is warm enough to stimulate activity. The crops of grasshoppers collected late in the day or after sunset are usually full. There is a feeding periodicity that is fairly regular under the usual daily sun regime.

Grasshoppers feed and drink in the absence of light in the laboratory. Under continuous bright or dim artificial light there is an irregular periodicity of feeding not related to a 24-hour period. Grasshoppers held in separate containers under the same regime may have different patterns of activity (Mongolkiti, 1973).

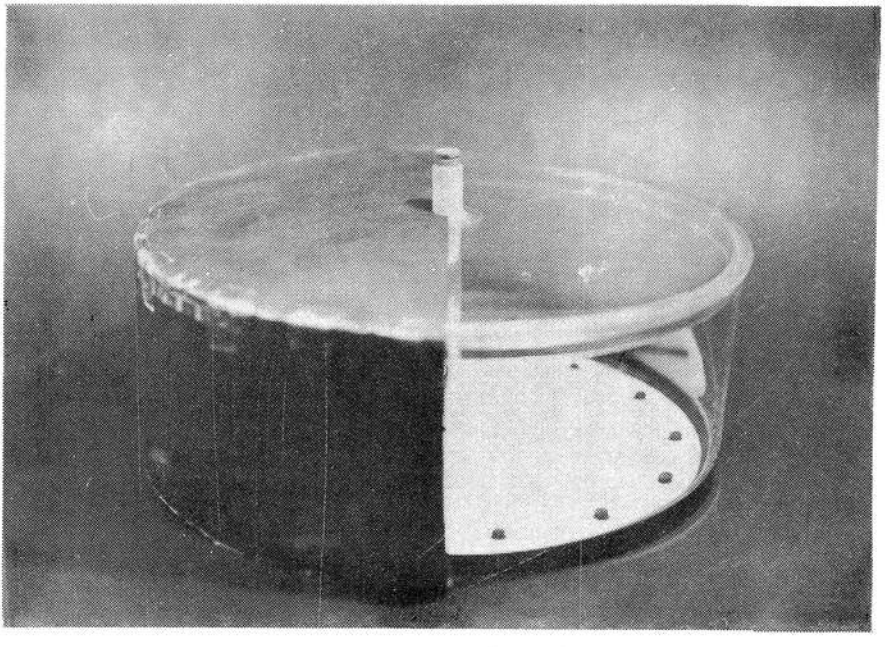


Figure 3. Plastic arenas with paper discs and outer cover used in feeding behavior experiments.

Grasshoppers were exposed to arrays of 4 tableted preparations, 2 with a phagostimulant and 2 without. Both preparations were palatable but the usual ratio of ingestion was 3:1 in favor of the phagostimulant. Six replicates were placed in a light-tight chamber and 6 were exposed to continuous light. The total feeding in the illuminated chambers was significantly greater (1.7:1) than in the dark ones but the ratio of feeding was about the same in each set, 5.6:1 in favor of the phagostimulant. Covering the compound eyes with an opaque paint did not cause a detectable decrease in total ingestion compared to unaltered grasshoppers but the ratio of feeding dropped to about 1:1. It would appear that general activity may be moderated by other receptors, and blinding the compound eyes decreases the searching activated by visual stimuli so a random feeding pattern occur. There is also a social stimulus, one feeding grasshopper stimulating others to feed. The mean food consumption of grasshoppers in groups of 3-5 is greater than that for grasshoppers held individually in the same conditions.

Grasshoppers respond to directed or point sources of light by orienting to and moving towards the light (positive photo-tropotaxis). With one eye covered they display the typical "circus movements" when illuminated from above. With intact grasshoppers, if more than one source of light is displayed and the intensity varied, response is always to the greater intensity. They discriminate differences in intensity of 2 lux, as fine as we could determine with available equipment. The heat or thermal radiation was equalized by water-filled containers as heat filters.

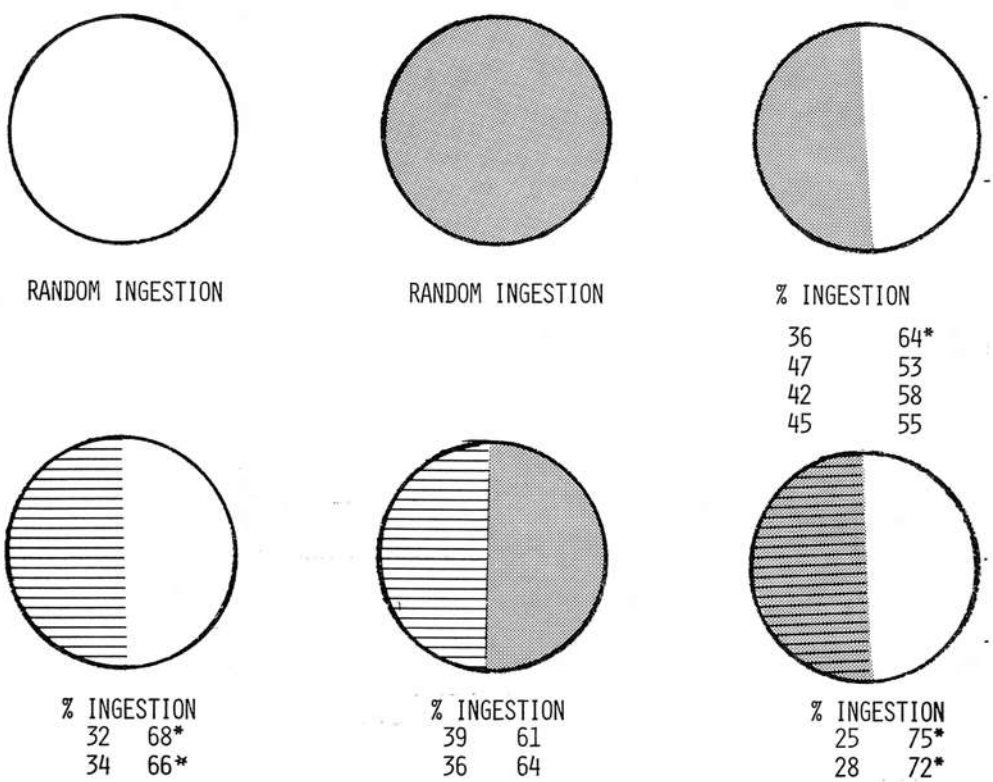


Figure 4. Percent ingestion of tablets displayed on different backgrounds. Stiple area is black, horizontal lines represent outer cover. *Indicates significant difference (P .05) by t-test).

The response to heat and light are separate. Grasshoppers align themselves for maximum or minimum exposure to the sun. They move to the shaded or sunlit side of an object in relation to the ambient temperature and the amount of radiation.

In the laboratory, 500 watt photoflood lamps which produced 2 x 10^5 lux and 1.2 c/cm^2 at 28 cm. from the source were directed at one end of a 1 m. long chamber. With water filled heat filters interposed, the grasshoppers were attracted towards the light. When the heat filter was removed, the grasshoppers retreated rapidly and moved to the shaded side of objects in the chamber. The grasshoppers could be induced to move back and forth across the chamber by moving the filter in and out.

Grasshoppers are negatively geo-tactic. The usual tendency is to crawl up objects and align their head upwards, even in the dark. They readily reorient if the surface upon which they are resting is realigned. However, if they are illuminated from underneath, they move downwards towards the source of illumination. Switching the light off and on or interposing appropriate filters causes the grasshoppers to reorient over and over again.

Thus, a grasshopper crawling up a plant to bask in the sun is responding to 3 different stimuli, in this case reinforcing each other, but in other circumstances over-riding each other.

Grasshoppers are most sensitive to or respond to radiations of light from 360 to 550 nm. That is, they moved toward or increased their activity when exposed to these wavelengths. There is less to little response from 600 to 1000 nm. or at 240 nm., the only wavelength below 360 tested. For example, a two-chamber reaction device (Fig. 5) allowed grasshoppers to respond to 2 simultaneous sources and filters. The complex transmission patterns of the filters (Figs. 6-8) make it difficult to identify exact wavelengths but the response is most pronounced in the lower range (Table 1).

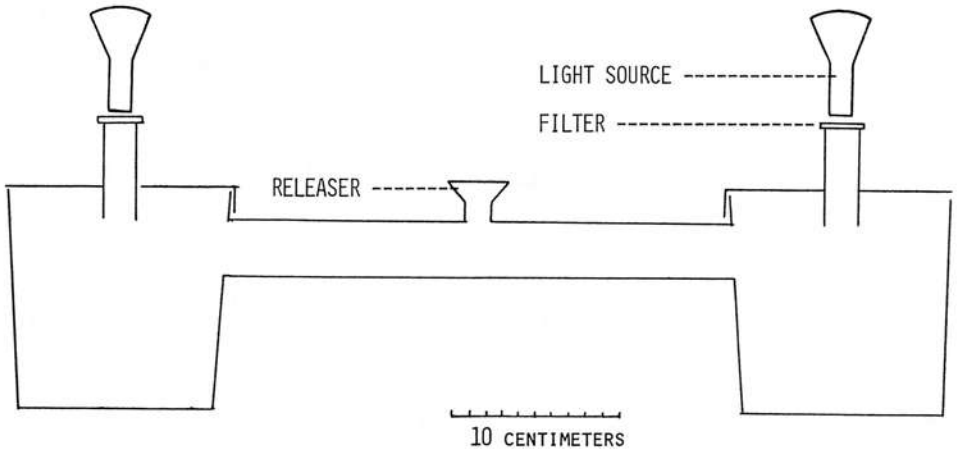
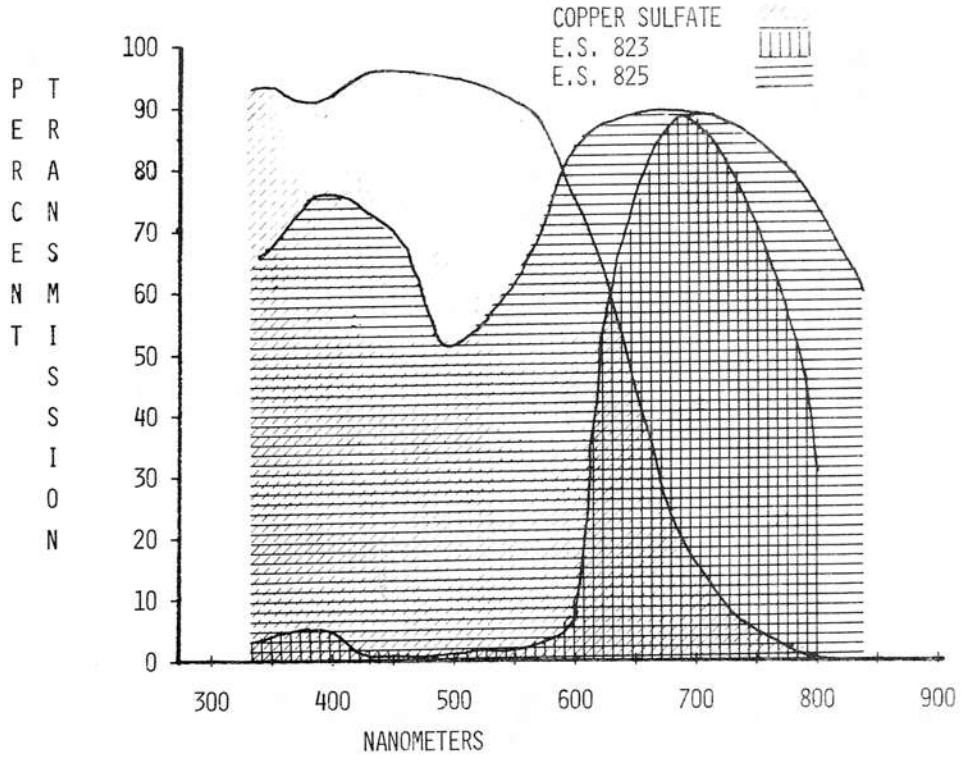
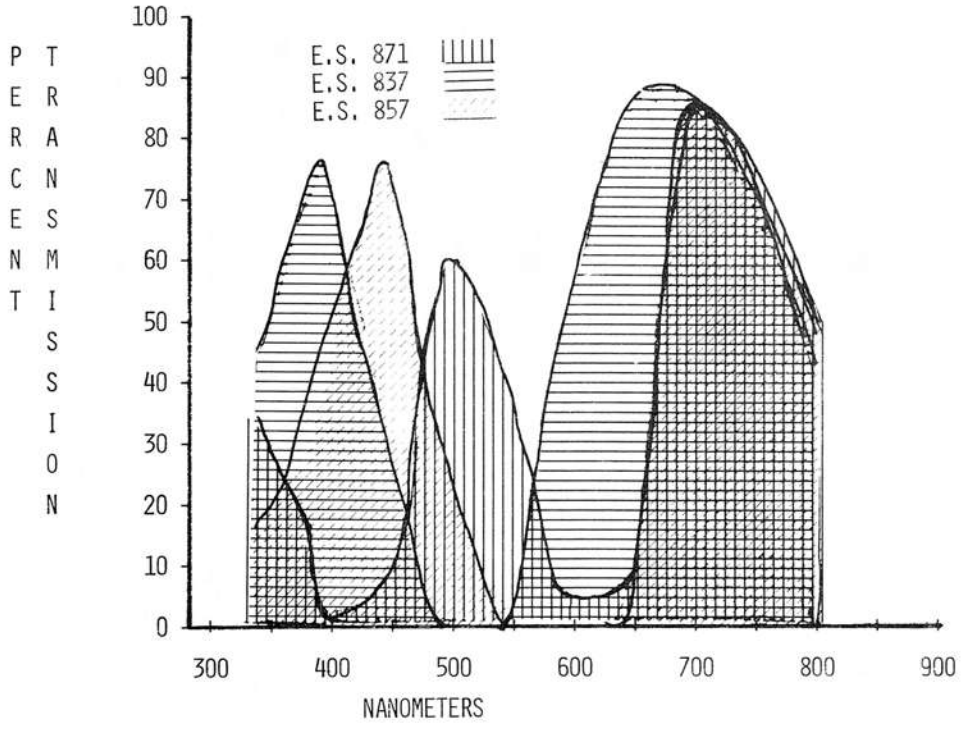


Figure 5. Two-chamber reaction device. Entire apparatus made of clear plastic covered with aluminium foil. Grasshoppers were released through center and travelled to chamber at either end.





Figures 6-7. Transmission curves of filters used in 2-chamber reaction device. Area beneath curves is filled in to emphasize overlap.

In view of the foregoing it is interesting that the reponse to artificial light under field conditions is quite limited.

Since grasshoppers are responsive to the range of wavelengths that includes the greens, colors associated with plants, there is a possiblity that color is a factor in host selection. Dyeing food materials, for example paper strips, always results in random selection with no influence by color (Table 2). Colored backgrounds upon which food material is displayed in laboratory or field experiments (Table 3) never indicates any influence by color.

Arrays of tablets were exposed in a chamber covered with black paper except for slits (2 x 7 cm.) on the top. The slits were covered with filters so that the tablets were each displayed in an area illuminated with a different wave length from 420 to 670 nm. There proved to be no significant differences in the amount of feeding among the colors.

Grasshoppers responded to visual patterns with the greatest positive response to contrasting vertical patterns. Any interface of contrasting patterns was effective, with the greater the linear interface, the greater the attraction. Narrow stripes down to about 3 mm. were more effective than equal areas of wide stripes with less linear interface (Mulkern, 1969). Grasshoppers ingested significantly more material arrayed on a vertical pattern than on a horizontal pattern in the greenhouse or in the field.

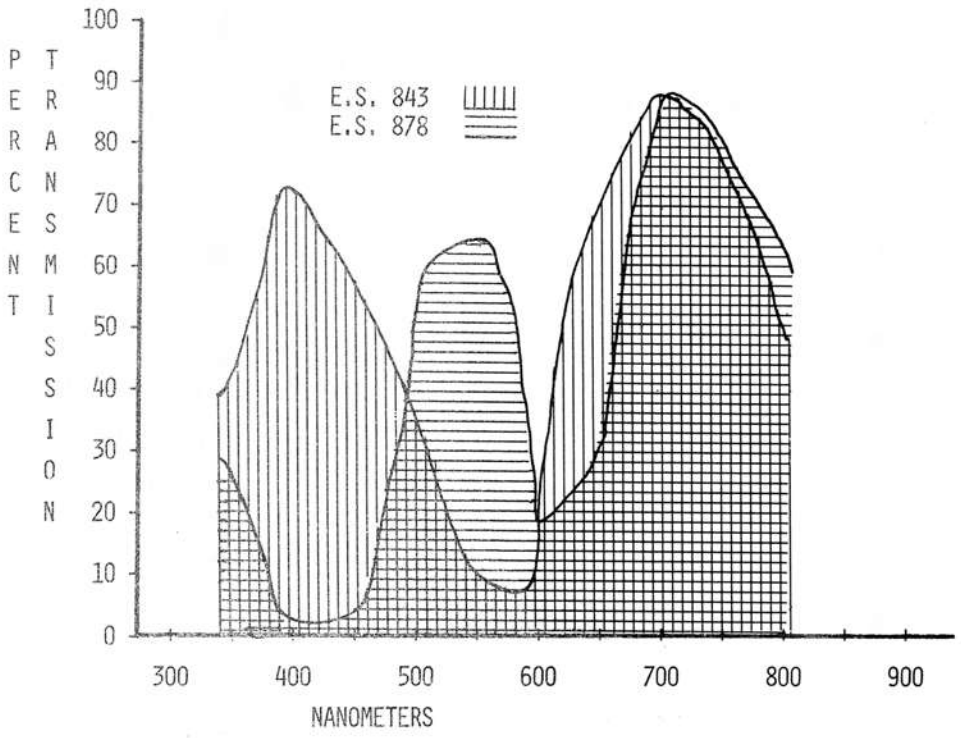


Figure 8. Transmission curves of filters used in 2-chamber reaction device. Area beneath curves is filled in to emphasize overlap.

TABLE1. Response of grasshoppers to filtered light[1] in 2 chamber apparatus

Filter	% Response n = 20 r = 10	
Pairs	*M. sanguinipes*	*M. confusus*
Copper sulfate	57*	30*
ES No 823	9	5
Copper sulfate	39	37
ES No 825	32	26
ES No 823	18	13
ES No 825	49*	38*
ES No 837	9	9
ES No 871	38*	39*
ES No 871	18	15
ES No 857	38*	37*
ES No 857	39*	37*
ES No 837	5	10
ES No 878	26	31
ES No 843	22	20

(1) Light source = Nicholas illuminators with intensities balanced.

* Significant difference (P = .05) between filters in pair. T−test.

TABLE 2. Ingestion of dyed paper (1) strips by 4 stadium *M. bivittatus.*

Color		Mean Ingestion in mg n = 10
Name	Methuen Notation	r = 8
Egyptian blue	21 C 7	8.3
Light turquoise	24 A 5	11.3
Copper green	26 B 6	10.1
Ocean green	27 C 7	7.3
Paris green	27 B 7	14.8
Apple green	29 C 7	7.9
Yellow	3 A 7	11.8
Brownish orange	6 C 6	9.0
Brown	8 E 5	3.7
Greyish ruby	11 D 6	4.4
Black	25 H 3	3.6
White	1 A 1	9.4

(1) Watman Nº 1 paper 1.3 x 5 cm. Schilling Food Colors in 1 M sucrose used to dye strips.

(2) Stakes were arrayed 30.5 cm apart around the perimeter of a 2.13 m diameter circle. Mainly adult and last instar. *M. femurrubrum* and *M. sanguinipes.* No significant differences among colors by analysis of variance (P = .05).

TABLE 3. Ingestion diet tablets(1) on stakes with colored panels exposed to field populations of grasshoppers(2).

Color		Mean Ingestion in mg
Name	Methuen Notation	n = 5
White	1′ A 1	39.6
Greyish green	30 C 4	34.7
Greenish grey	30 C 2	38.0
Greyish violet	15 C 4	27.8
Violet	15 D 5	46.9
Purple	15 C 6	50.3
Yellow	3 A 7	52.6
Bluish green	25 B 7	37.5
Green	26 D 7	31.9
Ocean green	27 C 5	47.3
Rose	11 A 6	51.3
Brownish violet	11 D 7	34.9
Dark red	10 C 7	56.3
Deep red	11 B 7	54.5
Reddish orange	7 B 8	44.0
Greyish turquoise	24 B 4	41.0
Porcelain (blue)	23 C 6	61.2
Greyish blue	20 D 5	39.8
Egyptian blue	21 C 7	44.6
Pastel pink	11 A 4	36.0
Brown	7 E 5	64.1
Black	25 H 3	61.5

(1) Basic diet carrier with. 25 g/g *Asclepias* extract + 2 %o chlorpyrifos.

(2) Stakes were arrayed 30.5 cm apart around the perimeter of a 2.13 m diameter circle. Mainly adult and last instar *M. femurrubrum* and *M. sanguinipes*.

No significant differences among colors by analysis of variance (P = .05).

DEVELOPMENT OF EDIBLE CARRIER

Plant extracts were bicassayed for nutritional and phagostimulatory agents by incorporating them into a basic diet carrier. This carrier was processed into trituration tablets to form a palatable material nutritionally adequate to sustain grasshoppers for several days (Mulkern and Toczek, 1970). The palatability and nutritional value were enhanced by the addition of plant extracts. Grasshoppers readily ingested these tableted preparations and could discriminate among different plant extracts and extract concentrations in the laboratory. The most active phagostimulant was the water extract of *Asclepias Syriaca.*

In competition with growing plants in laboratory and greenhouse tests, this preparation was found and ingested by grasshoppers. Since the diet preparation was to be tested as a carrier for control agents it was necessary to determine the effects of these on feeding behavior. Preparations with carbaryl, chlorpyrifos, or malathion caused no detectable differences in the initial feeding behavior of grasshoppers as compared to preparations without insecticides. However, within a few minutes after feeding, the grasshoppers ceased feeding and began to show symptoms of insecticide poisoning. Grasshoppers feeding on non-insecticide tablets continued feeding and ingested more material. In all experiments the grasshoppers eventually fed on the insecticide tablets and died.

There were no detectable differences in feeding among tablets with concentrations from .5 to 5 o/o carbaryl.

For example, ^{32}P- labelled tablets with and without 2 o/o carbaryl were tested in competition with growing vegetation in greenhouse cages. A single 50 mg. tablet was placed among an estimated 60-100 g. of barley and/or yellow sweet clover. The actual insecticide was 1 mg. (equal to 14 g/ha). Ten 4th stadium *M. bivittatus, M. differentialis,* or *M. femurrubrum* were introduced into the cages. Dead grasshoppers were collected each day and the radioactivity determined. Those alive at the end of 3 days were killed and the radioactivity determined. 40 to 70 o/o of the grasshoppers were radioactive, indicating that they had fed on the tablets (Table 4). During exposure, 80-100 o/o of the grasshoppers with carbaryl tablets died. Not all of the dead grasshoppers had significant radioactivity levels and may have died of causes other than carbaryl poisoning. Some died in the cages without cabaryl. For the tablets without carbaryl, dividing the weight loss by the number of grasshoppers with radioactivity more than twice background yielded an average ingestion of 1 to 3.4 mg. per grasshopper for 3 days. When exposed to the tablets alone, without vegetation, *M. differentialis* consumed an average of 16 mg. per day and *M. femurrubrum* 5.6 mg. per day. For the tablets with carbaryl, the ingestion per radioactive grasshopper was 130-200 micrograms for 2.6 to 4 micrograms of carbaryl per grasshopper in this confined environment.

Results from both laboratory and greenhouse tests indicated that the artificial diet preparations with *Asclepias* extract were readily ingested by grasshoppers. Thus, the next step was to determine if similar results could be obtained in the field with normal host plants. Initial tests were made in wood frame cages with saran screen covering. These could be folded for transport and were placed over various types of vegetation. In each cage artificial diet tablets with *Asclepias* extract and ^{32}P were placed on the ground or displayed on different types of stakes. The cages were stocked with grasshoppers and other insects swept from the surrounding area. All insects were removed and analyzed after 2 or 3 days.

Many grasshoppers, crickets, and tettigoniids ingested the materials as evidenced by radioactivity. Radioactive ants were found, otherwise no other insects were radioactive. Because wheat bran had been used as an edible carrier or bait for grasshopper control agents, ^{32}P-labelled bran flakes or tablets with bran in them were exposed in cages. Radioactive grasshoppers were found but the bran did not seem as effective as the diet material nor as easy to handle.

Tablets were then exposed in open plots with no barriers to grasshopper movements. The plots were each 25-square yards (20.9 m^2) situated in areas of dense or sparse vegetation of various composition. Three different rates (.75, 2.5 and 3.75 g.), 2 distribution patterns (dispersed or clumped), and 2 placements (on stakes or on the ground) were compared. For the dispersed method, 1, 2 or 3 tablets were glued to the top of flat wooden stakes. Twenty-five stakes were evenly placed 1/yd^2 in 5 x 5 row pattern. Tablets were glued singly to unpainted wood splints and laid on the ground at 1, 2, or 3 per square yard. The splints were used in accounting for the tablets as they were eaten.

TABLE 4. Counts/minute for ^{32}P for 10 grasshoppers exposed 3 days to ^{32}P-labelled tablets in greenhouse cages with growing vegetation.

	M. differentialis		*M. bivitattus*		*M. femurrubrum*	
	85*(1)	72	116*	315	2113	916
	68*	63	85*	109	675	657
	57	56*	50*	67	431	332
	53*	53	47*	64	286	352
	44*	26	42*	42*	184	128
	44*	21	41*	16	46	59
	37*	19	37*	15	43	28
	16*	15*	31*	14	14	15
	16*	11*	25*	10*	13	14
	8	8	19*	9	10	11
Plant	YSC	Barley	Barley	Barley	Barley	YSC
% Carbary in tablet	2	0	2	0	0	0

(1) Background level for all counts was 10 CPM. For control grasshoppers not fed on ^{32}P tablets, for all trials level was 13 CPM. Counts > 2X background considered evidence of radioactivity.

YSC = Yellow sweet clover. * = grasshopper dead before end of exposure.

For the clumped distribution 25, 50, or 75 tablets were glued to round wooden stakes placed in the center of a plot.

The stakes were covered with clear plastic caps to shield the tablets from rain and comply with safety procedures for handling ^{32}P.

The plots were sampled by erecting a portable saran screen 1.8 m. high that enclosed 9 square yards in the center (Mulkern *et al.* 1964). All insects within the enclosure were collected whith a vacuum sampling device. In addition, sweep nets were used to collect insects within 3 m of the outside perimeter of the plots. Pitfall traps were placed both within and outside the plots.

Plots were sampled after 2 or 7 days. The 7-days samples were of litle value as very few radioactive insects were recovered. The 2-days samples yielded many radioactive grasshoppers. In plots with the dispersed pattern, 20-26 o/o of the grasshoppers (30-70/plot) were radioactive. In the clumped patterns only 3-5 o/o of the grasshoppers were radioactive.

All of the tableted material was gone within 2 days in the dispersed pattern plots but most of the material in the clumped pattern plots was left at 7 days. Stakes with 50-75 tablets were left exposed for 28 days but there was litle evidence of feeding on the tablets. From analyses of timelapse films of stakes exposed in the field it appeared that grasshopers within 1-2 m. of the stakes readily moved towards and onto them but at greater distances there was little or no attraction.

The variation withing and among treatments precluded quantitative analyses but grasshoppers did readily find and feed upon the artificial diet material in presence of lush natural vegetation. Considering all of the plots, 25 of 28 species of grasshoppers, 3 species of crickets, and 4 of tettigoniids were radioactive (Table 5). Many ants were radioactive and ants were seen feeding on the tablets. Only 3 other insects, 2 sarcophagid flies and 1 reduviid adult, out of several hundred, were radioactive. The reduviid, a predator, may have fed on a radioactive grasshopper. Several radioactive spiders were collected. Six radioactive grasshoppers were found on spider webs, indicating that the spiders had fed on radioactive grasshoppers.

For field tests of control agents in edible carriers the tableted preparations with 2-5 o/o carbaryl or chlorphyrifos were attached to wood stakes or placed on the ground. In repeated tests in different habitats with increasing plot sizes from 300-3000 m^2 similar results were obtained. Large numbers of dead grasshoppers were observed in the vicinity of the insecticide preparations but sequential sampling revealed no significant differences in the populations 2 to 9 days after treatment. It was feid that the small size of the plots in relation to the surrounding area allowed for grasshopper movement into the plots.

The logistics of making and setting out large numbers of wooden stakes made enlarging the plot sizes increasingly more difficult. However, there seemed to be value in using the stakes as a visual stimulus to attract grasshoppers.

Black patterns were printed on both sides of white index stock paper which was then cut into strips. Each strip had 3 vertical white stripes on a black background. The

TABLE 5. Arthropods collected in plots whith ^{32}P–labelled tablets.

ORTHOPTERA
Acrididae
Gomphocerinae
*Aeropedellus clavatus**
*Ageneotettix deorum**
Amphitornus coloradus
Chloealtis conspersa
*Chorthippus curtipennis**
Eritettix simplex
*Orphulella speciosa**
*Pseudopomala brachyptera**
Oedipodinae
Pardalophora haldemanii
*Spharagemon collare**
Melanoplinae
*Hesperotettix viridis**
*Hypochlora alba**
*Melanoplus angustipennis**
*M. bivittatus**
*M. borealis**
*M. confusus**
*M. dawsoni**
M. femurrubrum
M. flavidus
*M. foedus**
*M. keeleri**
*M. sanguinipes**
Phoetaliotes nebrascensis
Cyrtacantharidinae
*Schistocerca lineata**
Tettigoniidae
*Conocephalus spp.**
*Neoconocephalus ensiger**
*Orchelimun spp.**
*Scudderiza pistillata**
Gryllidae
*Acheta assimilis**
*Allomobius fasciatus**
*Oecanthus nigricornis**

DIPTERA
Asilidae
Chironomidae
Culicidae
Muscidae
Sarcophagidae*
Syrphidae
Tabanidae
HOMOPTERA
Cercopidae
Cicadelliae
Fulgoridae
Membracidae
HEMIPTERA
Coreidae
Lygaeidae
Miridae
Nabidae
Pentatomidae
Reduviidae*
LEPIDOPTERA
Larvae and adults of both moths and butterflies
COLEOPTERA
Carabidae
Chrysomelidae
Cleridae
Curculionidae
Meloidae
Scarabaeidae
HYMENOPTERA
Formicidae*
Ichneumonidae
Vespidae
ARANEIDA
Many spiders, 6 with radioactive grasshoppers in web were radioactive

* Radioactive specimens captured.

bottom edge was folded diagonally twice to form a point and stapled (Fig. 9). The fold and staple weighted the end and curved the plane of the strip so that it would spiral-glide downward into the vegetation. Tablets were glued to the tops of stakes and they were distributed by hand-throwing in the plots. Results of tests in 3700 m^2 plots were similar to those obtained before. Up to this time tablets were prepared in a small trituration mold which limited production. A faster method was developed. A large mold made 31.5 g. slabs of the diet preparation which could be cut into 50 mg. tablets with a rotary slicer.

Carbaryl at at rate of 8 g. per hectare was applied to 8000 m^2 plots in the form of the basic diet carrier (2 o/o carbaryl) or a pelleted a apple pomace bait with 5 o/o carbaryl (Union Carbide Sevin Baits^R). The diet carrier was distributed as tablets attached to paper stakes or scattered loose on the ground and as uncut slabs. Control plots with no treatment, with paper stakes only, or with the basic diet tablets without insecticide attached to stakes or the ground were used for comparison.

The materials were evenly distributed, 1 stake for 3.3 m^2, 1 tablet for 8 m^2, 1 pellet for 2.7 m^2 and 1 slab for 500 m^2.

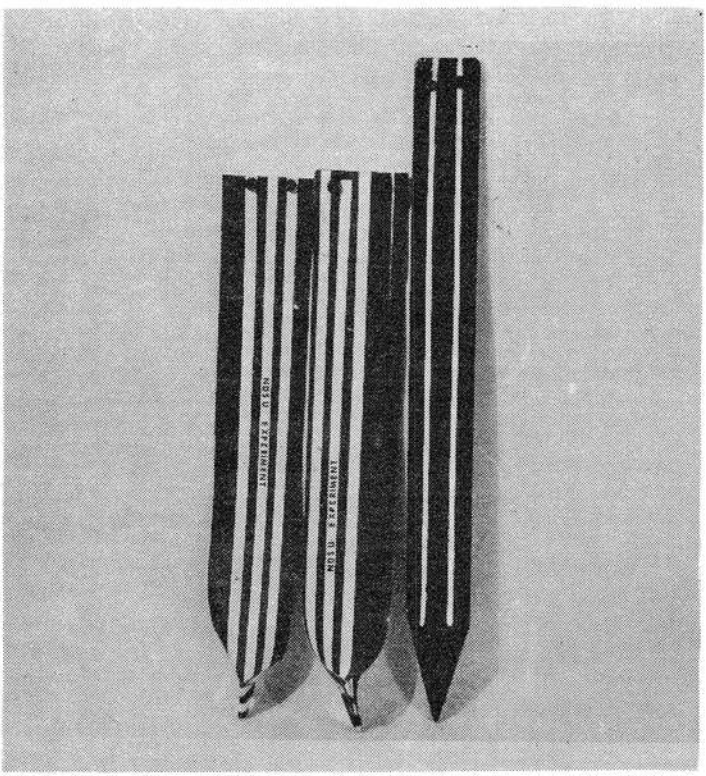


Figure 9. Paper (left) and wood (right) stakos used to display tablets in field experiments.

All plots were sampled weekly with a cage vacuum sampling device (Fig. 10) starting 2 weeks before treatment and continuing 5 weeks after treatment.

The results were inconclusive but interesting. The number of grasshoppers in all plots declined over the 9 days after treatment, although in most plots the differences were within the limits of sampling error (Table 6). The greatest differences were in the plots treated whith 2 o/o carbaryl-basic carrier with or without stakes, 2 to 5 times the decline in the other plots. The mean decrease in the non-insecticide plots was 5.4 grasshoppers per square meter. The mean decrease in the 2 plots with 2o/o carbamyl tablets was 21.8 grasshopper/m^2, a difference of 16.4 grasshoppers per square meter. The actual amount of insecticide was 1.2 mg. per square meter or 0.75 micrograms per grasshopper decrease. The plots with 2 o/o carbaryl slabs or 5 o/o apple pomace bait were no different from the non-insecticide plots.

The tablets on the stakes were gone within 9 days after application. As long as tablets were present grasshoppers could be seen feeding on them and freshly killed or dying grasshoppers collected. In some samples there were more dead grasshoppers per square meter than the original estimate of live grasshoppers. There were dead grasshoppers in the inmediate vicinity of the uncut slabs but no noticeable reduction in numbers. Approximately 60 o/o of the slab material remained 35 days after application.

The plot treated with 2 o/o carbaryl tablets on stakes was retreated with the same dosage 28 days after the first treatment, 19 days after the disappearance of the tablets from the first treatment. The mean number of grasshoppers was then 4.6 m^2 and it was reduced to 0.4/m^2 within 2 days. No further reduction in numbers was observed although some tablets remained for 35 days. It was difficult to sample low populations as the sampling error was large in comparison to the sample size. It also appeared that there was an irreducible minimum population that persisted despite treatment.

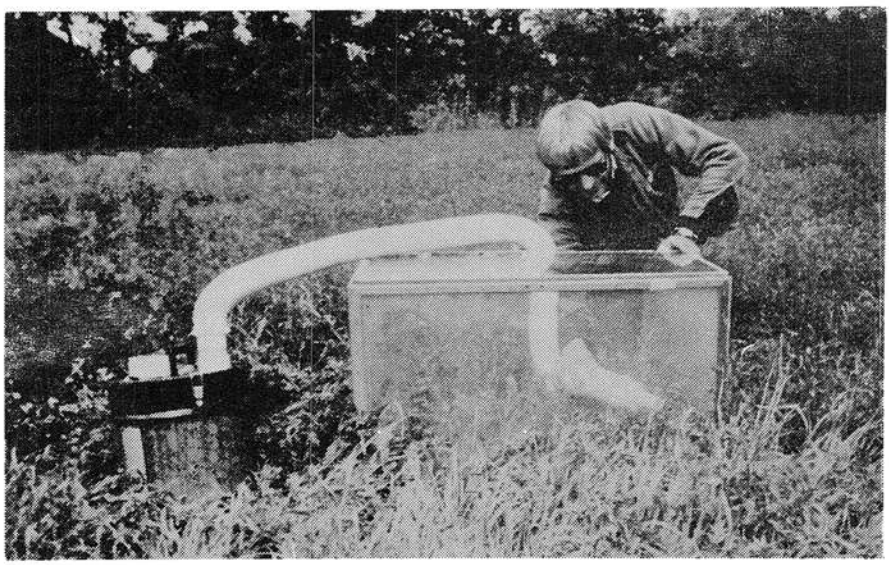


Figure 10. Cage-vacuum sampling device. Grasshoppers are collected into small plastic bags inside vacuum chamber at left.

Several experiments demonstrated that the effective range of the attractant preparations was less than 3 m, no matter what quantity of material was present. Even distribution of 30 to 80 mg. aliquots gave effective population suppression while the same quantity in 30–34 g. aliquots gave none.

The principle of sele tive suppression appeared to be effective and the method needed testing on large areas.

Previous experiments had shown that grasshoppers would feed on various papers if suitable phagostimulants were present. After testing many types it was determined that the consistency, stiffness, thinness, texture, etc., of newsprint paper was suitable for grasshoppers feeding. The paper itself was not ingested to any extent but the paper absorbed solutions with pphagostimulants and dried to a suitable texture. Newsprint was readily available in the form of discarded newspapers.

TABLE 6. Change in grasshopper numbers after treatment with edible carriers.

	Grasshoppers/m^2					
	Days after Treatment			%	Actual Decrease	
Treatment	0	2	9	Reduction(1)	%	Mean Grasshoppers/m^2
None	16.8^a	20.4^a	12.0^a	—	−29	4.8
Tablets	15.5^a	11.8^{ab}	9.0^b	19	−42	6.5
Stakes	8.1^a	5.0^a	5.9^a	0	−27	2.2
Tablets + Stakes	20.7^a	14.3^a	12.6^a	15	−39	8.1
Tablets + 2% Carbaryl	25.3^a	11.8^{ab}	4.5^b	75	−82	20.8
Tablets + Stakes + 2% Carbaryl	27.3^a	9.8^b	4.5^b	77	−84	22.8
Slabs + 2% Carbaryl	9.2^a	12.9^a	7.6^a	9	−17	1.6
Apple Pomace + 5% Carbaryl	11.8^a	12.3^a	6.7^b	21	−43	5.1

(1)Calculated by Abbott's formula. Means in rows with different superscript differ significantly (P = .05) determined by Duncan's Multiple Range Test. Actual insecticide rate was 8 g/ha.

The presence of insecticides did not alter the initial feeding response but did limit the amount of feeding as grasshoppers were affected by the insecticide.

Based on measurements of feeding and dissections of killed grasshoppers, about 2–4 mg. of treated paper (.25–.5 $cm.^2$) with 37–74 micrograms carbaryl, was the actual consumption for a medium-sized grasshopper like *M. sanguinipes*.

The most effective way to distribute the paper in the field was to shred it into strips which were in themselves attractant visual patterns for the grasshoppers.

In small plots treated with paper strips at 90 g/ha carbaryl, there was a reduction of 86 o/o in a population of 20 grasshoppers per square meter. The reduction occurred within 2 days. No further reduction was observed although paper strips were still present 60 days after distribution. No feeding on the strips was observed after 5 days exposure. In other experiments the palatability of the paper decreased after a few days of outdoor exposure.

The paper could be stored for months in sealed plastic bags at -18° or several weeks at room temperatures with no loss of palatability.

It appeared that exposure to sunlight was the principal cause for loss of palatability. This was in contrast to the diet preparations which retained paltability after several weeks exposure to sunlight. Rainfall sufficient to soak the paper also reduced palatability.

For field tests, the carrier was produced by soaking 20 cm. squares of salvaged newsprint (old newspapers) in a solution of *Asclepias* extract and sucrose with carbaryl suspended in it. The squares were pressed in a wringer to remove excess liquid and either freeze-dried or warm air-dried or a combination of both. The dried carrier contained 5 o/o carbaryl by weight.

A truck mounted shredder-blower (Fig. 11) was developed to distribute large quantities of the newsprint carrier. A paper shredder was mounted over a chamber with

Figure 11. Truck mounted shredder-blower for distributing paper edible carrier. Paper blown through duct at left.

an air duct extending from the chamber. A flexible hose connected the chamber to a gasoline or electric powered blower. The shredded paper fell into the chamber and was carried out the air duct "barrel" on the air stream provided by the blower. One 20 cm. square produced 45 strips about 4.5 mm. wide which were evenly distributed over a 2.5x4 m. area (about 4 strips/m^2). It was calculated that at 8.5 Kph, an even distribution of strips could be made at 4.5 ha/hr. This expectation was not reached.

Three sets of 2–ha plots were set out in grassland habitats. One plot in each set was treated with the edible carrier and 1 left untreated for comparison. The grasshopper populations were determined with a cage-vacuum sampling device prior to treating and 2 and 7 days after application. The number of paper strips/m^2 was also determined.

The grasshopper population varied among the 3 test sites (Table 7) with 28 species represented. Only 8 species were numerous.

The gasoline-powered blower was unreliable under actual operating conditions and because of difficulties with the blower, the strips were not distributed as evenly as expected and the actual dosages of insecticide altered. Instead of 2 hectare plots 123.5 g/ha, the rates ranged from 130 to 217 g/ha. and the plots from 1.1 to 1.9 ha.

There were significant reductions in the mean number of grasshoppers per square meter in the treated plots aat 2 and 7 days after application (Table 8). Using Abbott's formula the reduction ranged from 57-80 o/o but the sample variation influenced this as the formula is based on the change in populations in the treated and untreated plots. The differences in sample means in untreated plots were not significant.

Reduction calculated directly ranged from 68-74 o/o. The actual decrease was 6.4-16.8 grasshoppers per square meter.

All 8 numerous species were similarly reduced by the treatment. All species appeared to be affected by the treatment.

Because of the difficulties with the distribution of the shredded paper several modifications of the system were made. Newsprint end-rolls were obtained and cut to 20 cm. widths. The paper was processed into continuous rolls which could be fed into the shredder. Molasses was substituted for the plant extracts as a phagostimulant. The blower system was modified so that the shredded paper fell into the airstream of a large fan mounted on the back of a truck (Fig. 12).

Plot sizes were increased to 4 ha. The populations varied among the test sites (Table 9) with 32 species represented. Only 11 were numerous.

There were significant reductions ($P = .05$) in the mean number of grasshoppers in the treated plots at 2 and 7 days after application (Table 8).

Plots K and L received 2.6 cm. of rain on the 4th day after application. This did not seem to have any effect on population reduction as most of the deaths had occurred by then. The smaller decrease in plot L is the result of blower malfunction that caused uneven distribution of the paper leaving significant areas untreated. An analysis of the frequency of sample numbers indicated the mean was influenced by the variance resulting from large samples being picked up in the untreated portions rather than a general failure to reduce the populations. Plot I received 1 cm. of rain 12 hours after treatment. There was a noticeable decrease in the palatability of the strips as little feeding or mortality occurred after the first day. Most of the decrease resulted from the few hours of feeding before the rain. Some of the reduction in control plot H may have resulted from movements of grasshoppers into the treated plots.

The actual grams of insecticide (Table 10) per mean grasshopper decrease ranged from 0.77 to 2.7 x 10^{-3}. The mean of all plots was 1.46 x 10^{-3} compared to a calculated 8.56-12.85 x 10^{-3} assuming 99,o/o control at the recom mended rate of 1.2 to 1.68 kg/ha.

TABLE 7. Species composition of grasshopper population in 1975 test plots.

Species	Percent of Total(1) Richland A	Slope C	Slope E
Aeropedellus clavatus	+		
Ageneotettix deorum	+	11	+
Amphitornus coloradus	+	+	+
Chloealtis conspersa			+
Chorthippus curtipennis	+	+	+
Eritettix simplex	+	+	+
Opeia obscura	6	22	+
Orphulella speciosa	9	+	+
Phlibostroma quadrimaculatum		6	
Pseudopomala brachyptera			+
Arphia conspersa	+	+	
A. pseudonietana	+	+	+
Encoptolophus sordidus		+	
Pardalophora haldemanii	+		
Spharagemon collare	+		+
Trachyrhachys kiowa		7	+
Hesperotettix viridis	+		+
Melanoplus angustipennis	+		
M. bivittatus	+		+
M. confusus	+		
M. dawsoni	+		+
M. femurrubrum	+	+	+
M. flavidus	+		
M. foedus (2)	+	+	+
M. infantilis		11	+
M. keeleri	+		+
M. sanguinipes	65	11	44
Phoetaliotes nebrascensis	+	21	46

(1) + = present, less than 5o/o, no figure means species not present.
(2) may include *M. packardii.*

TABLE 8. Mean grasshopper numbers in plots treated with 5% carbaryl in edible carrier newsprint strips.

Plots	Hectares Treated	Carbaryl g/ha	Grasshoppers/m^2 *Days after treatment*(2) 0	2	7	% Reduction(1)	*Actual decrease* %	m^2	Location	Date Treated
A	1.45	173.0	9.31^a	2.45^b	2.87^b	72	69	6.4	Richland Co.	30 July 1975
B		0	6.09^a	5.81^a	6.79^a		0	0		
C	1.93	130.0	22.47^a	8.89^b	5.67^b	80	75	16.8	Slope Co.	12 August 1975
D		0	13.09^a	11.97^a	17.71^a		0	0		
E	1.15	217.4	14.19^a	7.28^b	4.57^b	57	68	9.6	Slope Co.	12 August 1975
F		0	10.50^a	13.62^a	8.02^a		24	2.5		
G	4.05	123.5	12.23^a	1.77^b	0.89^b	89	93	11.3	Richland Co.	6 July 1976
H		0	8.07^a	8.49^a	5.51^b	32	32	2.6		
I	4.05	123.5	12.60^a	3.31^b	2.47^b	65	80	10.1	Richland Co.	13 July 1976
J		0	9.80^a	7.42^a	11.01^a		0	0		
K	4.05	123.5	14.00^a	1.73^b	0.93^b	90	93	13.1	Slope Co.	28 June 1976
L	4.05	123.5	13.35^a	4.01^b	3.64^b	68	73	9.7		
M		0	16.25^a	11.15^a	13.44^a		17	2.8		

(1) Calculated from Abbott's formula.
(2) Means in any row not superscripted by same letter differ significantly (P= .05) determined by Duncan's Multiple Range

TABLE 9 Species composition of grasshopper populations in 1976 test plots.

Species	*Percent of Total*[1]			
	Richland		*Slope*	
	G	I	K	L
Aeropedellus clavatus	+	+	+	+
Ageneotettix deorum	21	5	30	16
Amphitornus coloradus	49	6		
Chorthippus curtipennis	+	+		
Eritettix simplex	+	+		
Mermeria maculipennis				+
Opeia obscura	+	19		+
Orphulella speciosa	+	8		+
Philoboetroma quadrimaculatum			+	13
Psoloessa delicatula				+
Arphia conspersa			+	+
A. pseudonietana	+	8	+	+
Encoptolophus sordidus	+			+
Hadrotettix trifasciatus			+	+
Metator pardalinus			+	
Pardalophora haldemanii	+			
Spharagemon equale			6	+
Trachyrachis kiowa		+	+	10
Hypochlora alba			+	5
Hesperotettix viridis	+			
Melanoplus angustipennis	+	+		
M. bivittatus		+	+	+
M. bowditchi				+
M. confusus	+	+		
M. femurrubrum		+		+
M. flavidus		+		
M. foedus[1]	+	+	+	+
M. infantilis			31	21
M. keeleri	+	+		
M. sanguinipes	21	43	15	10
Phoetaliotes nebrascensis	+	+	+	9
Schistocerca lineata	+			

(1) + = p resent, less than 5%, no figure means species not present.
(2) Mav include *M. packardii.*

TABLE 10. Mean decrease in grasshopper numbers in treated plots.

	Plot	Decrease Grasshoppers/m^2	Carbaryl g X 10^{-3} Per Grasshopper Decrease
1975	A	6.4	2.70
	E	9.6	2.26
	C	16.8	0.77
1976	L	9.7	1.27
	I	10.1	1.22
	G	11.3	1.09
	K	13.1	0.94

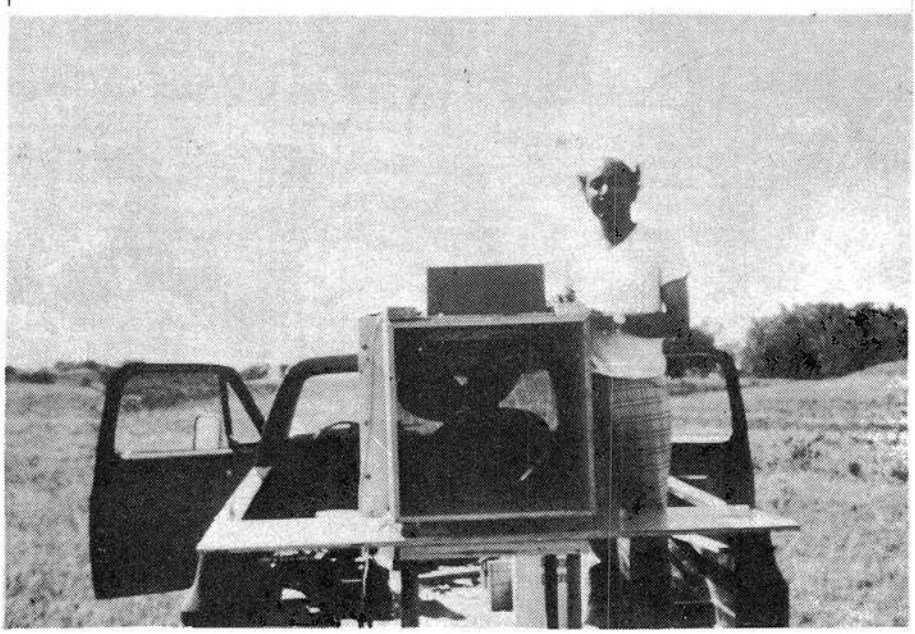


Figure 12. Truck mounted shredder-blower for distributing paper edible carrier. Paper blown out by fan.

The cost for materials was:

	Per Acre	Per Hectare
Paper	.197	.486
Molasses	.237	.585
Carbaryl	.338	.835
TOTAL	$0.772	$1.906

Because less than one-half of the paper was consumed the amount of carbaryl can likely be reduced. Further tests will be made for this.

Other than grasshoppers, the only insects observed feeding directly on the paper strips were crickets, tettigoniids, and ants. Predators and scavengers, including crickets, tettigoniids, and ants, as well as carabids, cicindelids, reduviids, etc., were indirectly affected by eating dead or dying grasshoppers. Grasshoppers themselves fed on dead or dying comrades and recycled the insecticide.

Other insects such as bees, flies, lepidopterans, hemipterans, etc., were not affected by the application of insecticide in the edible carrier.

Returning to the Performance Index, some speculations may be made. Granting 99 o/o control to carbaryl at 1.12 kg/ha. gives a PCE of .88. This would be lowered if the non-target population reduction were considered. The Performance Index calculates to 0.116.

Granting 90 o/o control to the edible carrier, the PCE becomes 7.29. The reduction for non-target effects would be lower than for broadcast application. The Performance Index becomes 3.82.

The cost of production of the edible carrier is not included. It is difficult to calculate. The cost of application is also not included. These may lower the PI of the edible carrier but the carrier still appears promising, especially because of the selectivity of control.

Each treated paper strip is equally effective in killing grasshoppers that feed on it. However, the total number of grasshopper killed in a large area is directly related to the density and distribution of the paper strips. The dosage rate and the number of grasshoppers killed per m^2 can be determined by controlling the density and distribution of the paper strips. Thus, selective suppression, including limited or controlled reduction in population densities, can be obtained. This differs from broadcast applications where dosages lower than recommended rates often result in disproportionately lowered effectiveness; that, is the rate of control drops of rapidly as the amount of insecticide is decreased.

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